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PHILIPPINES

MANGROVE MAPPING FOR THE VERDE ISLAND PASSAGE



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Cover photo: This mangrove forest is part of a Marine Protected Area in Balibago, Verde Island Passage in the Philippines. Photo: © CTSP / Tory Read



Mangrove Mapping for the Verde Island Passage, Philippines

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Mangrove Mapping for the Verde Island Passage

Introduction

As part of the Coral Triangle Support Program (CTSP) for the Verde Island Passage (VIP), there was a need to determine the areal extent and distribution of mangrove cover over time. Such spatial information should feed into CTSP proponents' decision-making and planning with respect to mangrove conservation and rehabilitation. This would also contribute to CTSP's climate change adaptation goal by providing the basis for climate-change adaptation, strategic planning of local government units and national agencies to guard against storm surges and enhance their fisheries management. The specific objectives of the mangrove and fishpond mapping for CTSP are as follows:

- determine the areal extent of mangrove forest cover in the 1990s and in the 2010s;
- determine by best effort the areal extent of fishpond areas in the 1990s and in the 2010s;
- detect change of mangrove cover into fishponds and into other land use types; and
- contribute spatial information to the Climate Change Adaptation Goal of the Coral Triangle Support Program.

The following sections describe: the data used to accomplish the objectives; the methods used in interpreting these data into their map form; the results; assessment of the accuracy of the results and some conclusions.

Data Used

There were two main sets of data used for this mapping activity. One is a dataset on the satellite imagery and the other was dataset derived from field survey for groundtruthing and validation purposes. The latter comprised the training and testing data.

Satellite Image Data

The mapping of the mangroves had a two-pronged approach: 1) to map the most recent areal extent of the mangroves in the VIP; and 2) to quantify the extent of transition from mangrove stands into another land cover type. To accomplish these, we procured satellite imageries circa 1990 and circa 2010, and used an existing dataset of Quickbird Imageries, which we borrowed from another CI project. Mangroves and fishponds along the Verde Island Passage (VIP) were classified from Landsat 4 TM imageries, ALOS AVNIR-2 imageries, and Quickbird imageries. The image dates and spatial resolutions are shown in Table 1.

Prior to georeferencing, the scenes that have the same image acquisition dates were mosaicked (e.g., Landsat images 116-50 and 51 dated 18 June 1989, ALOS images 225373320-50 dated 18 April 2010, and ALOS images 230333320-30 dated 22 May 2010). The 18 June 1989 image mosaic was used as the reference image for georeferencing all the other images during the image-to-image registration process. The georeferencing resulted to all images having a common spatial reference in UTM Zone 51 projection WGS 84 datum. The Quickbird images were resampled to a resolution of 1 m x 1 m because further processing using the original

submeter spatial resolutions led to memory allocation problems. The final and georeferenced images used in the classifications are shown in Figures 1 and 2.

Table 1. List of images used in the image classification

| Image | Path/Row | Acquisition Date | Spatial Resolution |
|--------------|---|-------------------|--------------------|
| Landsat 4 TM | 115-051 | 18 March 1993 | 30 m x 30 m |
| Landsat 4 TM | 116-050, 116-051 | 18 June 1989 | 30 m x 30 m |
| Landsat 4 TM | 116-050 | 25 January 1989 | 30 m x 30 m |
| ALOS AVNIR-2 | 194303330 | 17 September 2009 | 10 m x 10 m |
| ALOS AVNIR-2 | 225373320, 225373330, 225373340, 225373350 | 18 April 2010 | 10 m x 10 m |
| ALOS AVNIR-2 | 230333320, 230333330 | 22 May 2010 | 10 m x 10 m |
| Quickbird | | 04 November 2008 | 0.6 m x 0.6 m |
| | | 10 January 2011 | 0.5 m x 0.5 m |
| | | 14 January 2010 | 0.5 m x 0.5 m |

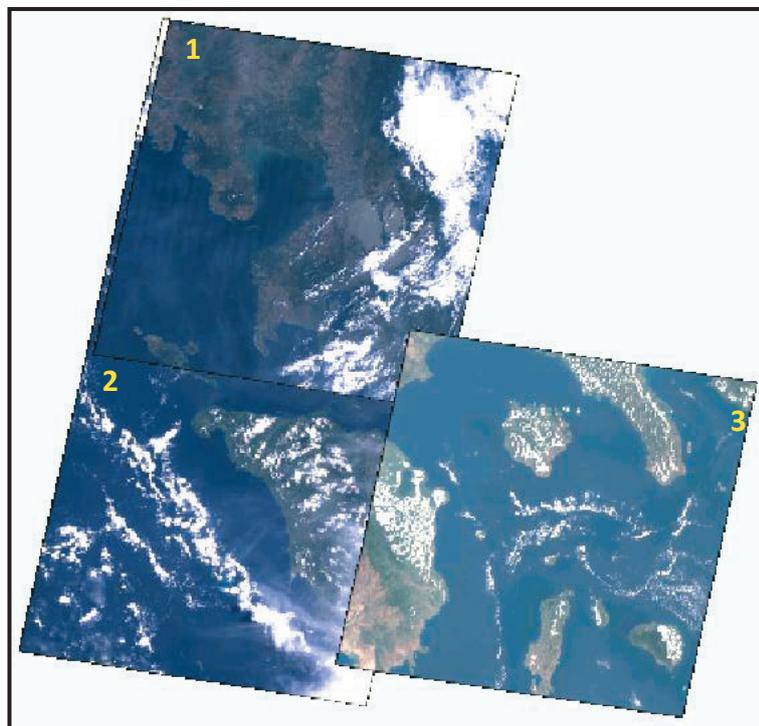


Figure 1. Landsat 4 TM images: (1) 25 January 1989; (2) 18 June 1989 mosaic; (3) 18 March 1993.

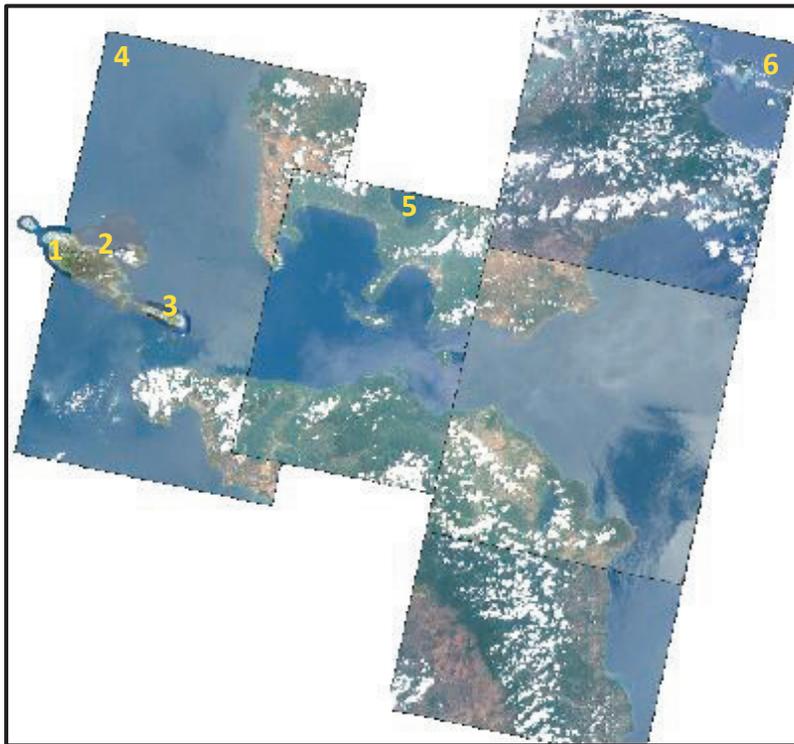


Figure 2. Quickbird images: (1) 10 January 2011; (2) 04 November 2008; (3) 14 January 2010; and ALOS images: (4) 22 May 2010 mosaic; (5) 17 September 2009; and (6) 18 April 2010 mosaic.

Training and Testing Data

Field survey data for those areas in Oriental Mindoro, Batangas, and Occidental Mindoro within the VIP were collected during a series of surveys done in March, April and May 2011. The compiled field data were divided into two sets, one for training the classifier and the other for accuracy assessment so as to test the reliability of the results. Using the training data points as reference and visual interpretation, 571 training polygons were created for the circa 1990 classification, while 923 training polygons were used for the circa 2010 classification. The accuracy of both classifications was assessed using 154 validation points.

To maintain consistency in the interpretation of the two circa, the same sets of training data and testing data were applied to each circa year. However, since a time-series of satellite data was involved and, therefore, land cover change was certain, the training data had to be adjusted depending on the image being interpreted. For instance, there were some training pixels that the analyst assigned to a particular class in ca. 1990 images, but will not be the same set of pixels for ca. 2010 images, because these were visually identified as having had undergone land cover change already. There were also instances, which had a training pixel identified in the ca. 2010 image, but none in the ca. 1990 image. This was mainly because more details were detected in the ca. 2010 images than in the ca. 1990 images owing to the higher spatial resolution.

Methodology

The mapping of the mangroves, fishponds and other land classes when derived from satellite imagery comprise of several steps. The mapping methodology is summarized in Figure 3 as a diagram.

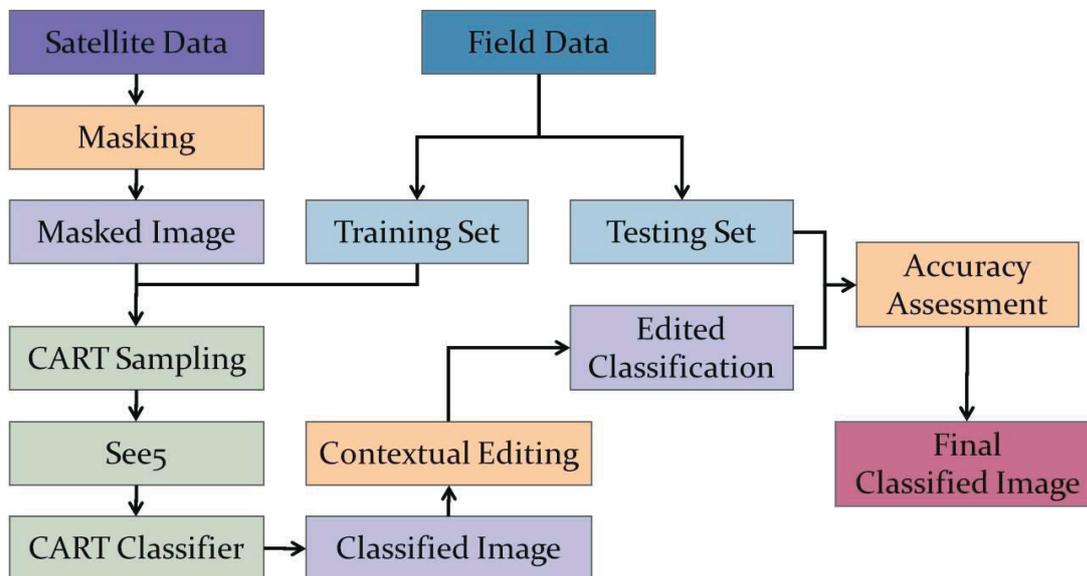


Figure 3. The mapping methodology.

Each scene with a different image acquisition date was classified separately since the pixel values vary across different image scenes. After mosaicking and georeferencing the images, as previously described in the *Satellite Image Data* part of this report, ArcGIS was used to manually draw polygons around the areas of interest. This shapefile was then converted to raster and later on served as the mask to exclude the unnecessary areas, thus simplifying the classification and reducing possible misclassifications.

Using the training dataset, collected from the field data, as guide, training polygons were created in Erdas to represent the various classes. Mangrove and fishpond were the two main classes required by the project. However, based on our training dataset and field observations other adjacent classes needed to be included such as built-up, bare areas, grassland, other vegetation, cropland, salt bed, vegetated salt bed, bare salt bed, open water, inland water, cloud, and shadow. The fishpond class was also further subdivided into three subclasses – ‘fishpond’, ‘vegetated fishpond’, and ‘dry fishpond’. The vegetated fishpond class included fishpond areas that seemed to already be covered with non-mangrove vegetation (grass or brush) but still retain the delineation of the fishpond dike. The dry fishpond class included the fishpond areas that appeared to be waterless on the images. It was necessary to separate the fishpond and salt bed classes into the said subclasses since each subclass varied substantially from each other in terms of spectral signature. Furthermore, we wanted to identify the seemingly idle fishponds (i.e., vegetated or dry fishponds) for possible mangrove reforestation.

The training polygons comprised the training set, were then rasterized and then used in the CART Sampling tool to generate the needed input for the See5 software, which in turn created the decision tree. Decision tree classification is non-parametric and uses a hierarchical representation of classification rules. Several parameters can be utilized by the decision tree classifier to aid in the creation of rules, such as the spectral bands, the training dataset, and digital elevation model (DEM). In this study, however, we did not use a DEM since there was no available high-resolution DEM to effectively complement the classification.

The decision tree was then used as input for the CART Classifier along with the previously created image mask, resulting to the initial classified image. To each classified image, we applied a majority filter to eliminate most of the speckles. Each filtered classified image was then converted to polygon shapefile in ArcGIS. All the circa 1990 polygons were combined into one shapefile using the Merge tool in ArcGIS. This procedure was also applied to the circa 2010 polygons. Hence, we have two shapefiles for each circa.

After which, a certain degree of contextual editing was applied to correct the grossly misclassified areas for both shapefiles. Examples of such misclassifications were 'fishpond' wrongly classified as 'inland water' or 'open water' and vice-versa, 'vegetated fishpond' misclassified as 'grassland' and vice-versa, and 'salt field' misclassified as 'built-up' and vice-versa. These classification errors were mainly due to the close similarities in spectral signature of the corresponding classes. Contextual clues such as spatial location and shape or pattern were used in manually correcting the classified images. For instance, pixels classified as 'open water' but were distinctly located within a fishpond area were then re-labeled as 'fishpond' during the editing process.

The correction of the misclassifications gave rise to an edited version of the classified image, the edited classification. The error matrix was then derived based on the intersections of the final edited classification and the validation points coming from the testing data. The matrix comprised of the column values of particular classes of validation points (e.g., mangrove as seen on the ground) and row values of particular classes of the edited classification. The column values served as the "reference" observations of the classes, while the row values served as the "classified" values coming from each pixel of the satellite imagery. Based on this generated error matrix, the producer's accuracy¹, user's accuracy², overall accuracy³, per class kappa, and overall kappa⁴ were computed in Excel.

Results

Figures 5 to 14 show the resulting maps coming from the final classified images for the entire VIP, Batangas, for Lubang Island Group, and portions of both mainland Occidental Mindoro and Oriental Mindoro for circa 1990 and circa 2010. The corresponding areas in hectares per map class for both image dates are listed in Tables 2 to 6.

¹ Producer's accuracy is the probability that a pixel truly belonging to a class, as indicated by its reference class, is classified into that class.

² User's accuracy is the probability that a pixel classified into a class truly belongs to that class.

³ The overall accuracy is the ratio of the correctly classified samples to the total number of reference or validation samples.

⁴ Kappa is the statistical measure of inter-rater agreement, taking into account the agreement occurring by chance.

For each table, the total area corresponding to classes for the 1990 does not equal or come close to the total area for 2010 classifications. This is because they came in different spatial resolutions. The 1990 shapefile was derived from the Landsat classification with a 30 m x 30 m spatial resolution, while the 2010 shapefile was derived from the ALOS-Quickbird classification with 10m x 10m and 1m x 1m spatial resolutions, respectively. Therefore, the resulting boundaries for the 1990 and 2010 classifications did not appear coincident, with the Landsat classifications resulting to larger total areas. However, the boundary edges mainly contained non-mangrove and non-fishpond areas such as built-up, bare area, grassland, other vegetation, cropland, open water, and inland water. We can then reasonably say that the resulting mangrove and fishpond areas were more likely comparable than highly different. Vegetated and bare salt beds were not detected from the Landsat classifications, perhaps, because of their low resolution.

Looking at the VIP classification maps, the most extensive mangrove patches were located in the municipalities of Calapan City and Pola in Oriental Mindoro. However, some of the most extensive fishpond areas were also in these two municipalities. For the entire VIP (Table 2), the mangrove areas were greater than the combined fishpond areas ('fishpond' + 'dry fishpond' + 'vegetated fishpond') in both 1990 and 2010. However, if we look at the net increase from 1990 to 2010, mangroves increased by 266 hectares while the combined fishpond areas increased by 309 hectares.

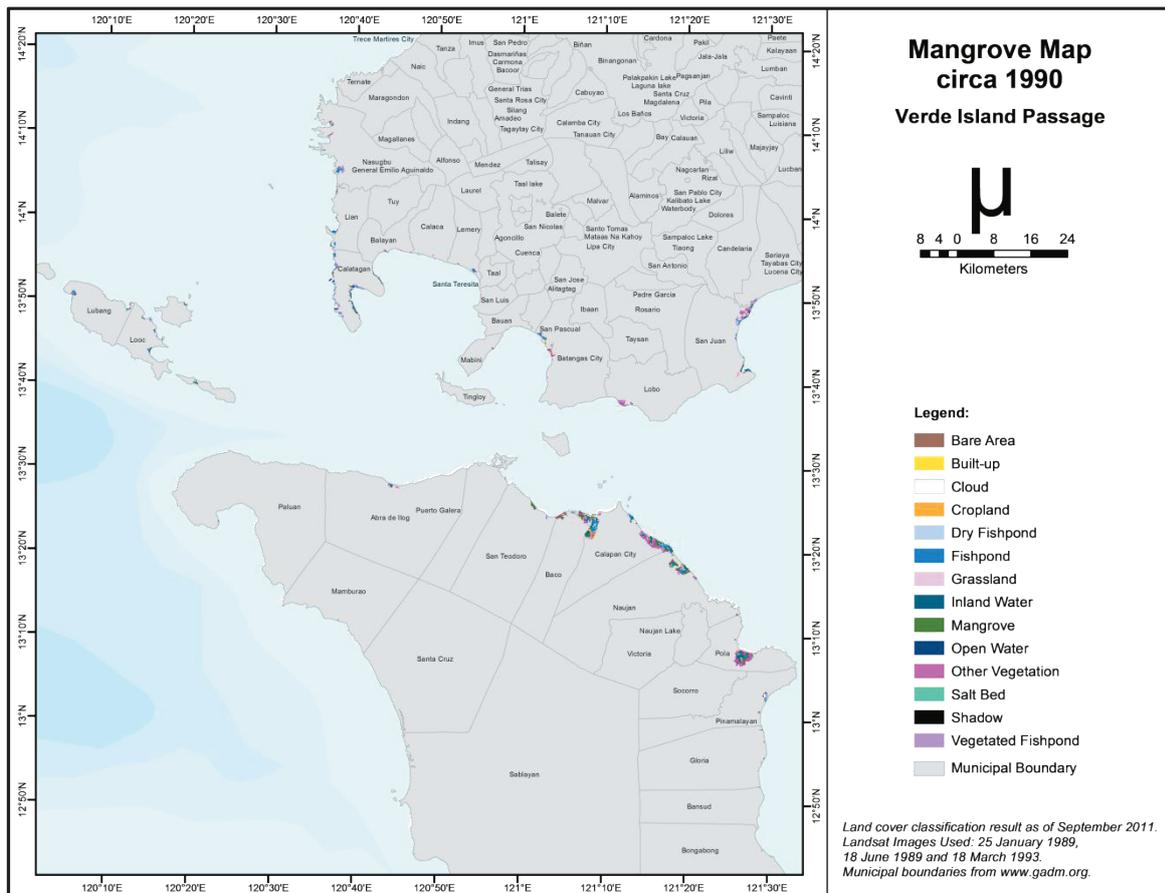


Figure 5. Circa 1990 map of the Verde Island Passage.

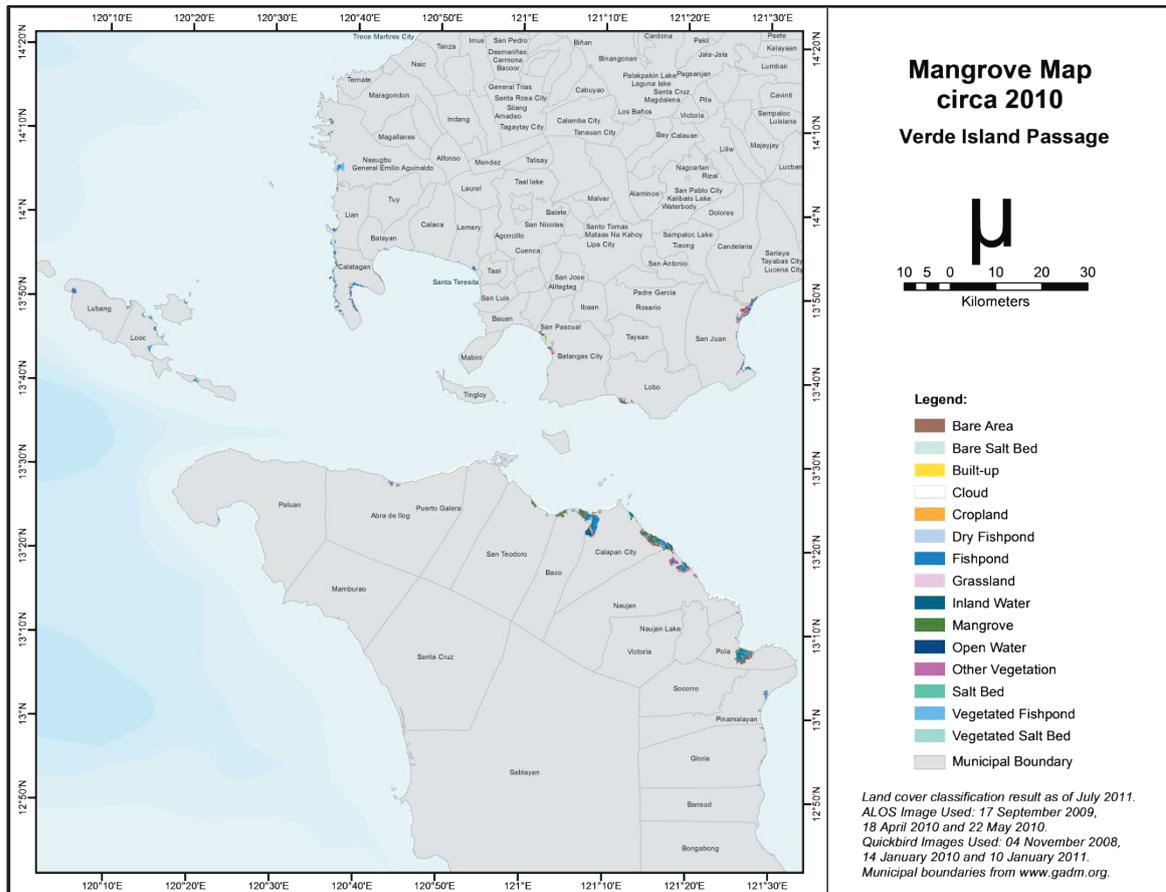


Figure 6. Circa 2010 map of the Verde Island Passage.

Table 2. Per class areas for Verde Island Passage classification

| Class | 1990 Area (hectares) | 2010 Area (hectares) |
|--------------------|-----------------------------|-----------------------------|
| Built-up | 57.15 | 210.46 |
| Cloud | 83.25 | 1.31 |
| Shadow | 13.14 | 0.00 |
| Mangrove | 2,317.60 | 2,583.13 |
| Fishpond | 1,224.63 | 1,717.59 |
| Vegetated Fishpond | 227.61 | 388.11 |
| Dry Fishpond | 503.28 | 158.58 |
| Bare Area | 39.78 | 133.51 |
| Grassland | 1,535.57 | 1,045.72 |
| Other Vegetation | 1,715.71 | 1,044.88 |
| Cropland | 110.43 | 202.70 |
| Salt Bed | 3.15 | 10.92 |
| Vegetated Salt Bed | 0.00 | 0.22 |
| Bare Salt Bed | 0.00 | 7.37 |

| Class | 1990 Area (hectares) | 2010 Area (hectares) |
|---------------------|----------------------|----------------------|
| Open Water | 423.00 | 327.59 |
| Inland Water | 608.44 | 604.21 |
| Total Area = | 8,862.73 | 8,436.30 |

For the Batangas province, several of the classified mangrove areas were in the municipality of Calatagan. However, this was also the locality in Batangas which experienced the most conversion to fishponds by 2010. Aside from increase in the 'fishpond' class, another very noticeable difference between the two classifications was in the built-up areas, particularly in Batangas City. In fact, the combined fishpond areas ('fishpond' + 'dry fishpond' + 'vegetated fishpond') experienced net decline for the entire province, but the built-up areas increased by about 100 hectares within the mask areas only. This does not include yet the areas, which are not adjacent to mangroves or fishponds, which most likely had an even greater degree of urbanization. The state of mangroves in this province was positive, however, increasing by 119 hectares from 1990 to 2010. This may be attributed to mangrove reforestation activities in the municipalities of San Juan and Lobo.

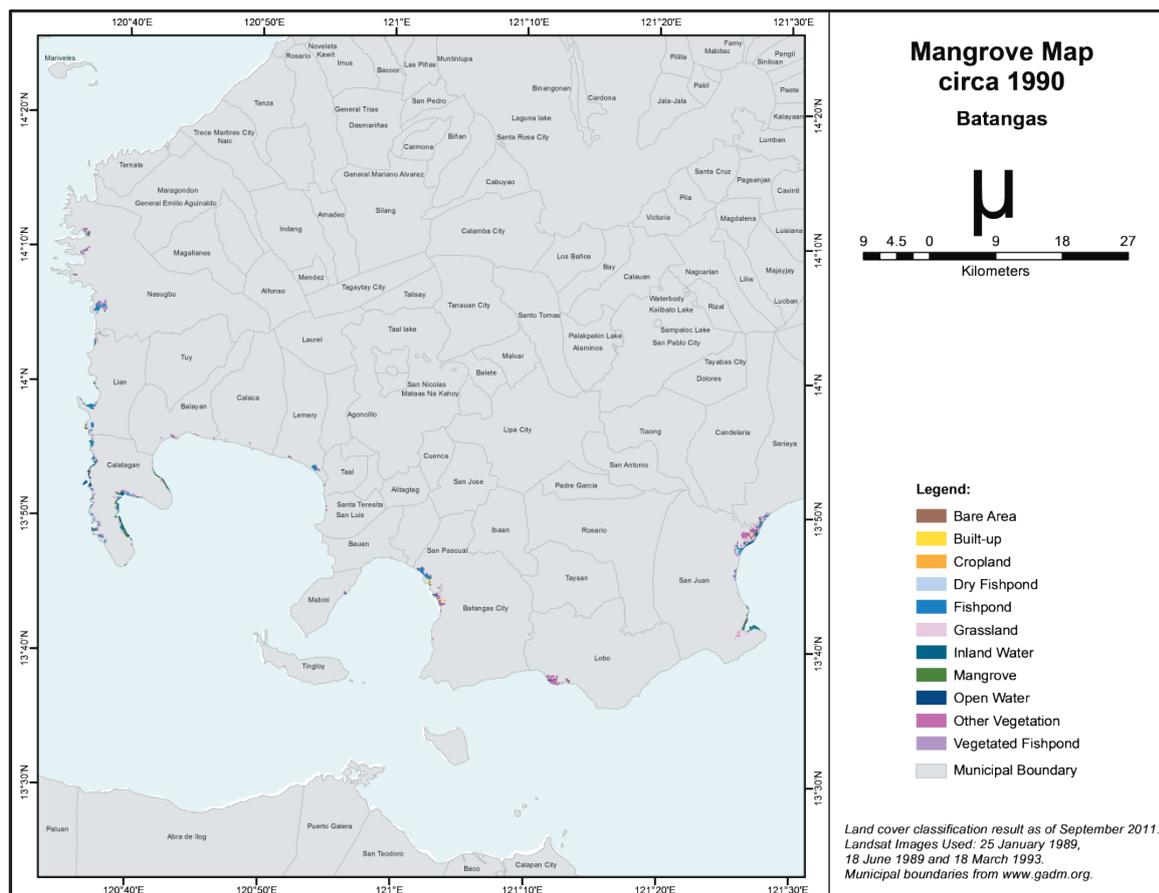


Figure 7. Circa 1990 map of the province of Batangas.

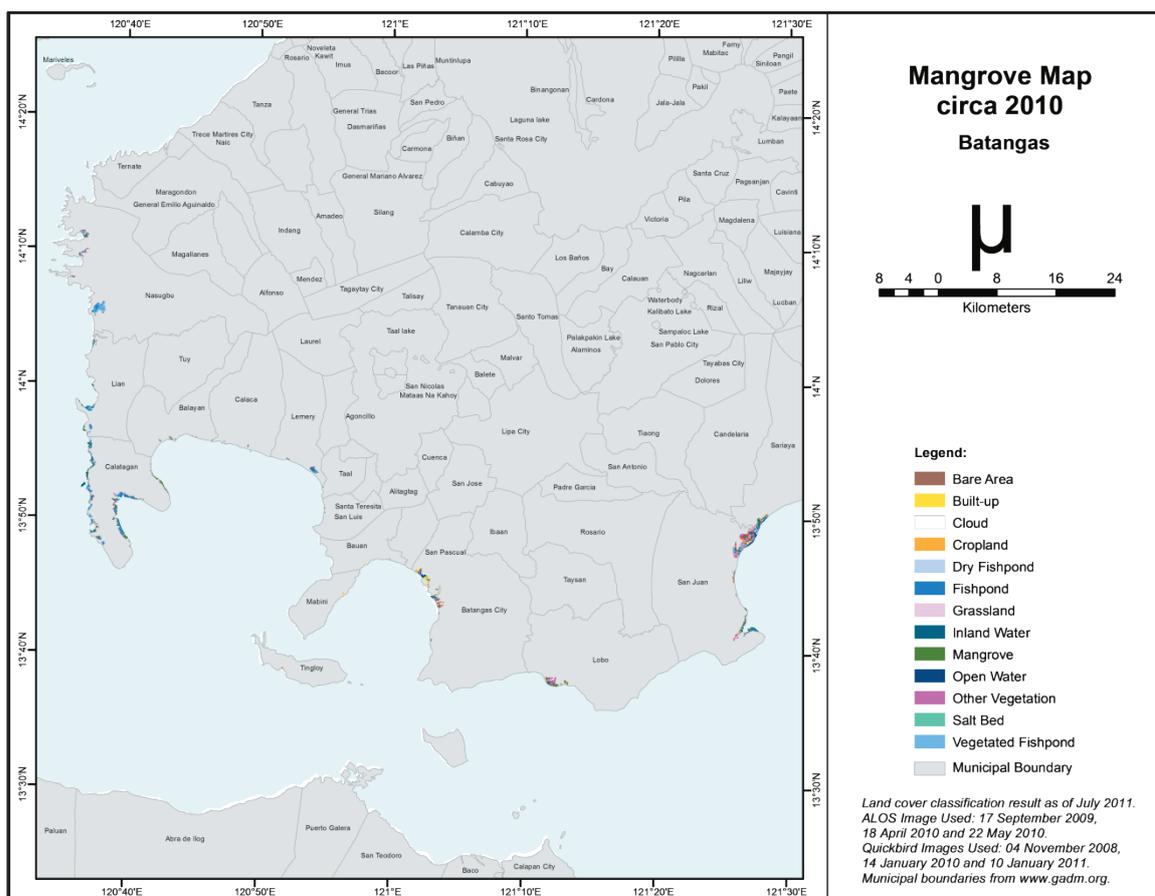


Figure 8. Circa 2010 map of the province of Batangas.

Table 3. Per class areas for the Batangas province classification

| Class | 1990 Area (hectares) | 2010 Area (hectares) |
|---------------------|---------------------------------|---------------------------------|
| Built-up | 39.87 | 148.60 |
| Cloud | 0.00 | 0.22 |
| Mangrove | 543.87 | 663.21 |
| Fishpond | 475.56 | 528.75 |
| Vegetated Fishpond | 138.51 | 213.45 |
| Dry Fishpond | 199.53 | 62.62 |
| Bare Area | 25.38 | 101.50 |
| Grassland | 835.65 | 529.79 |
| Other Vegetation | 535.41 | 347.88 |
| Cropland | 5.40 | 91.17 |
| Salt Bed | 0.00 | 3.83 |
| Open Water | 327.33 | 230.94 |
| Inland Water | 99.18 | 100.60 |
| Total Area = | 2,968.51 | 3,022.55 |

The Lubang Island Group (LIG) classification, which was based on 1m-resolution Quickbird images, was the most detailed among all the classified areas within the VIP. The salt beds in this classification were more accurately represented compared to the Landsat and ALOS classifications, because the features were seen most clearly at high resolution.

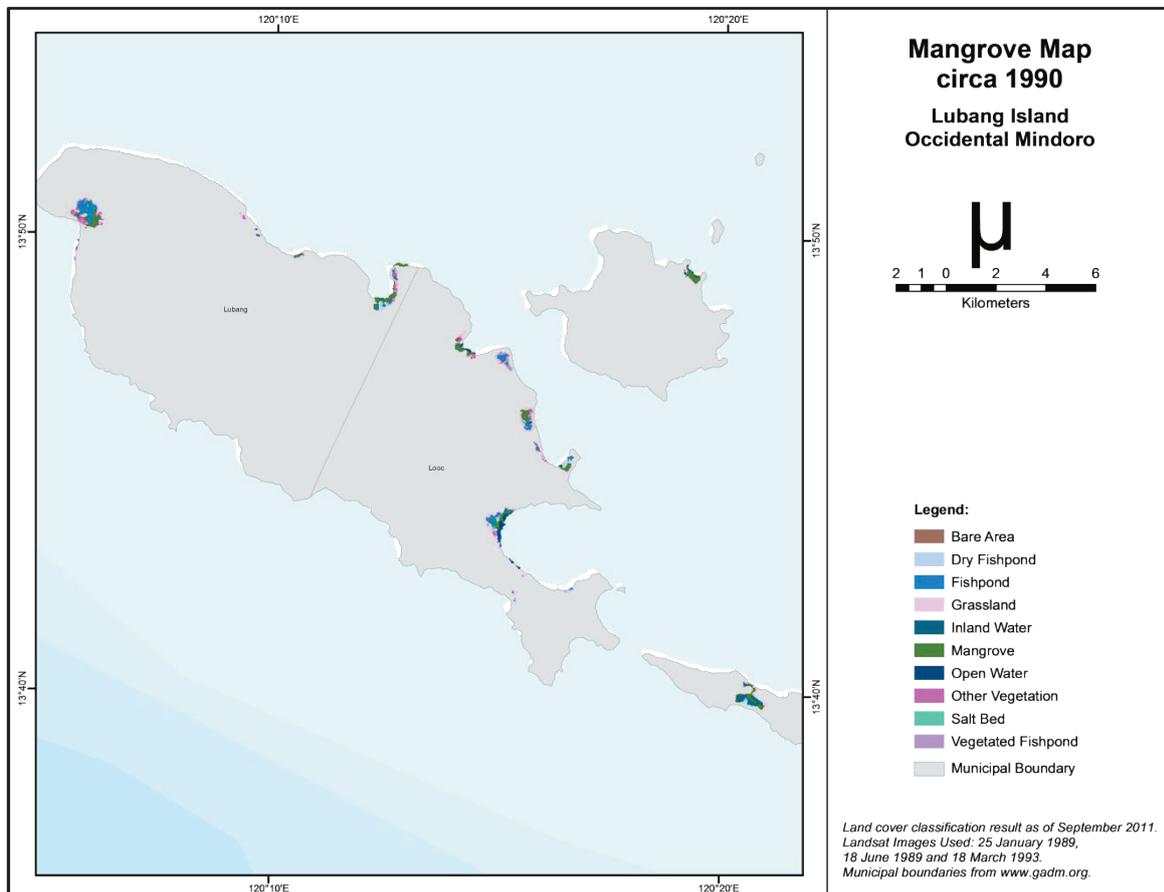


Figure 9. Circa 1990 map of LIG, province of Occidental Mindoro.

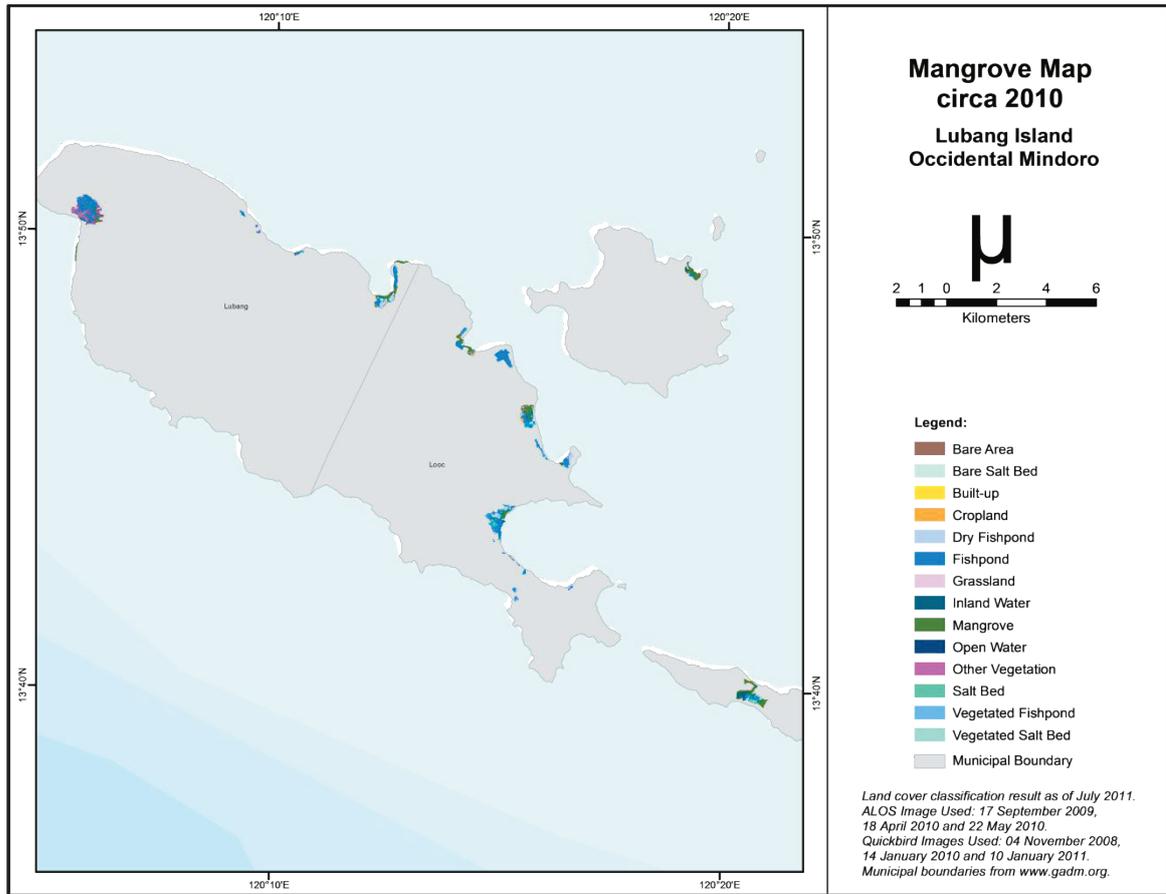


Figure 10. Circa 2010 map of LIG, province of Occidental Mindoro.

Table 4. Per class areas for the Lubang Island Group (LIG) classification

| Class | 1990 Area (hectares) | 2010 Area (hectares) |
|--------------------|---------------------------------|---------------------------------|
| Built-up | 0.00 | 2.35 |
| Cloud | 2.70 | 0.00 |
| Mangrove | 142.92 | 108.71 |
| Fishpond | 78.57 | 184.11 |
| Vegetated Fishpond | 15.30 | 4.00 |
| Dry Fishpond | 20.16 | 36.06 |
| Bare Area | 4.41 | 14.25 |
| Grassland | 123.84 | 10.20 |
| Other Vegetation | 45.81 | 27.61 |
| Cropland | 0.00 | 4.03 |
| Salt Bed | 3.15 | 7.05 |
| Vegetated Salt Bed | 0.00 | 0.22 |
| Bare Salt Bed | 0.00 | 7.37 |
| Open Water | 34.65 | 7.01 |

| Class | 1990 Area (hectares) | 2010 Area (hectares) |
|---------------------|----------------------|----------------------|
| Inland Water | 26.37 | 16.13 |
| Total Area = | 497.88 | 429.10 |

The province of Occidental Mindoro, covering municipalities of Paluan and Abra de Ilog and excluding Lubang Island Group (LIG), had two mangrove/fishpond patches, one for each of the two municipalities. The one in Paluan was mostly fishpond but the one in Abra de Ilog had extensive mangrove areas, doubling in area from 1990 to 2010.

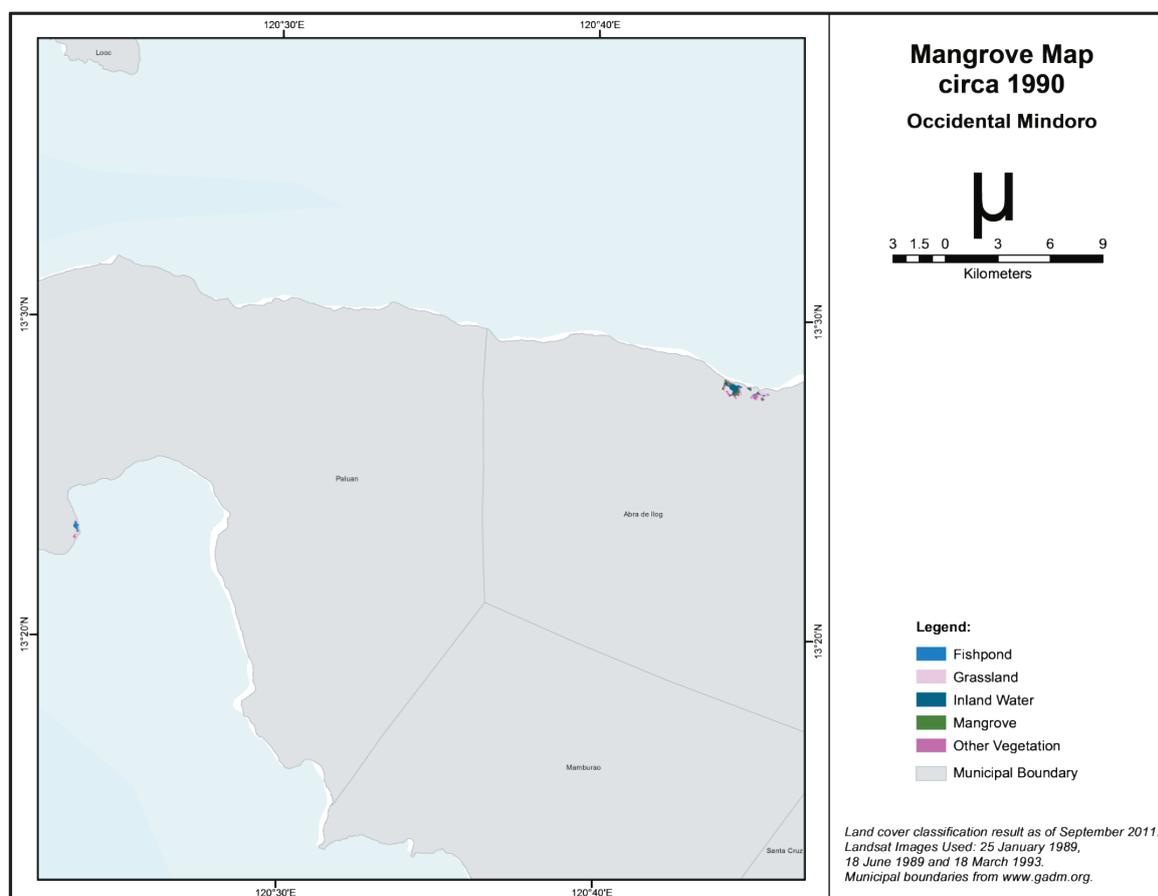


Figure II. Circa 1990 map of the province of Occidental Mindoro, excluding Lubang.

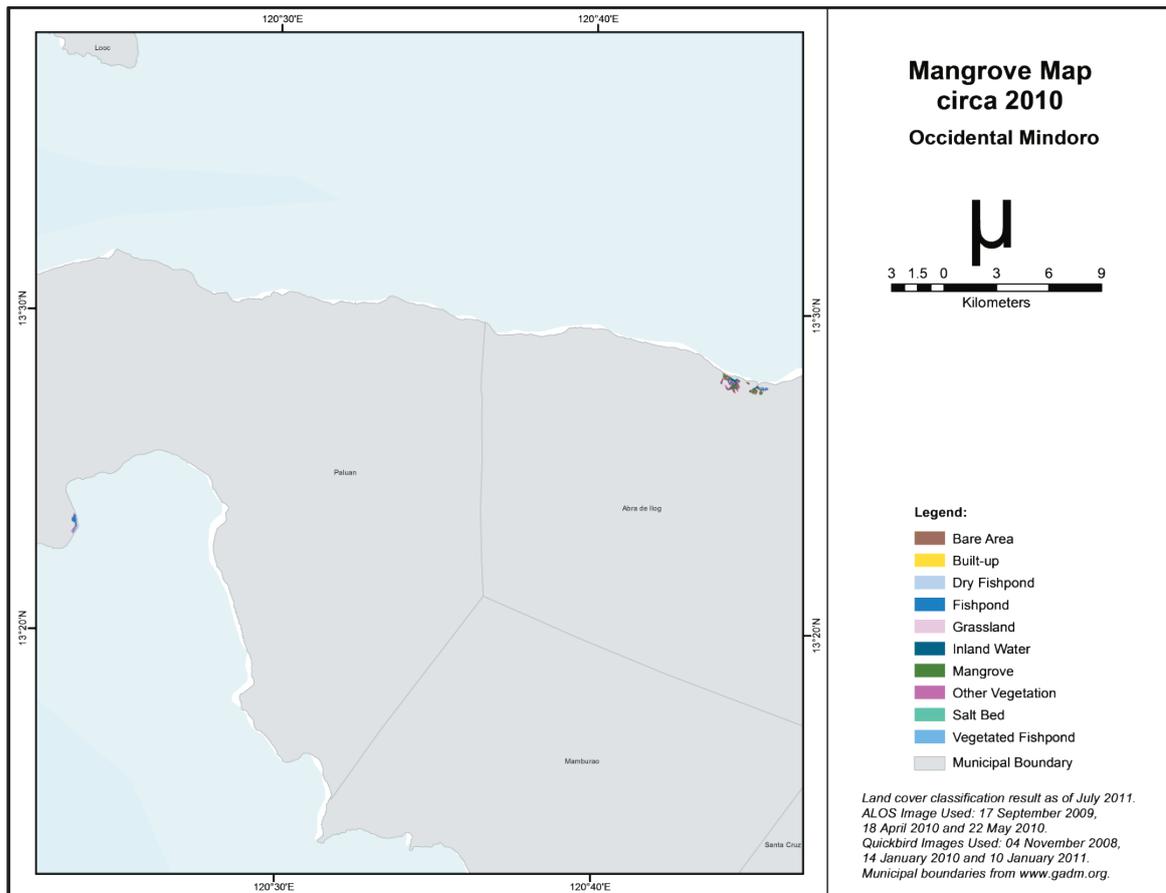


Figure 12. Circa 2010 map of the province of Occidental Mindoro, excluding Lubang.

Table 5. Per class areas for the Occidental Mindoro classification

| Class | Area (hectares) | Area (hectares) |
|---------------------|------------------------|------------------------|
| Built-up | 0.00 | 0.49 |
| Mangrove | 20.61 | 40.39 |
| Fishpond | 10.80 | 16.81 |
| Vegetated Fishpond | 0.00 | 0.60 |
| Dry Fishpond | 0.00 | 0.27 |
| Bare Area | 0.00 | 0.52 |
| Grassland | 43.20 | 17.08 |
| Other Vegetation | 23.67 | 28.08 |
| Salt Bed | 0.00 | 0.04 |
| Inland Water | 28.35 | 11.59 |
| Total Area = | 126.63 | 115.87 |

Oriental Mindoro, including municipalities of Puerto Galera, San Teodoro, Baco, Naujan, Pola, Pinamalayan and Gloria, and the city of Calapan, was the province with the most municipalities containing mangroves and/or fishponds. The most extensive mangrove patches for this province were found to be in Calapan City. However, this city also had extensive fishpond areas compared to the other municipalities.

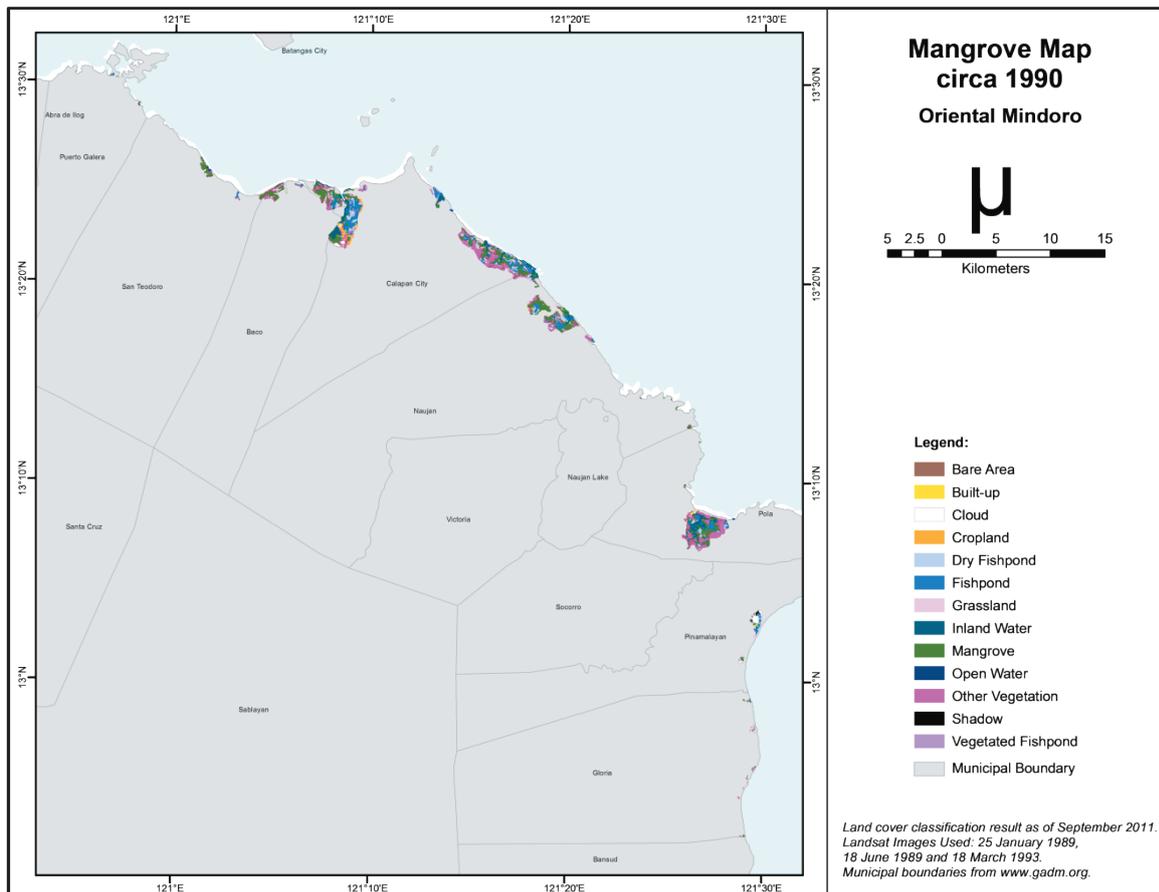


Figure 13. Circa 1990 map of the province of Oriental Mindoro.

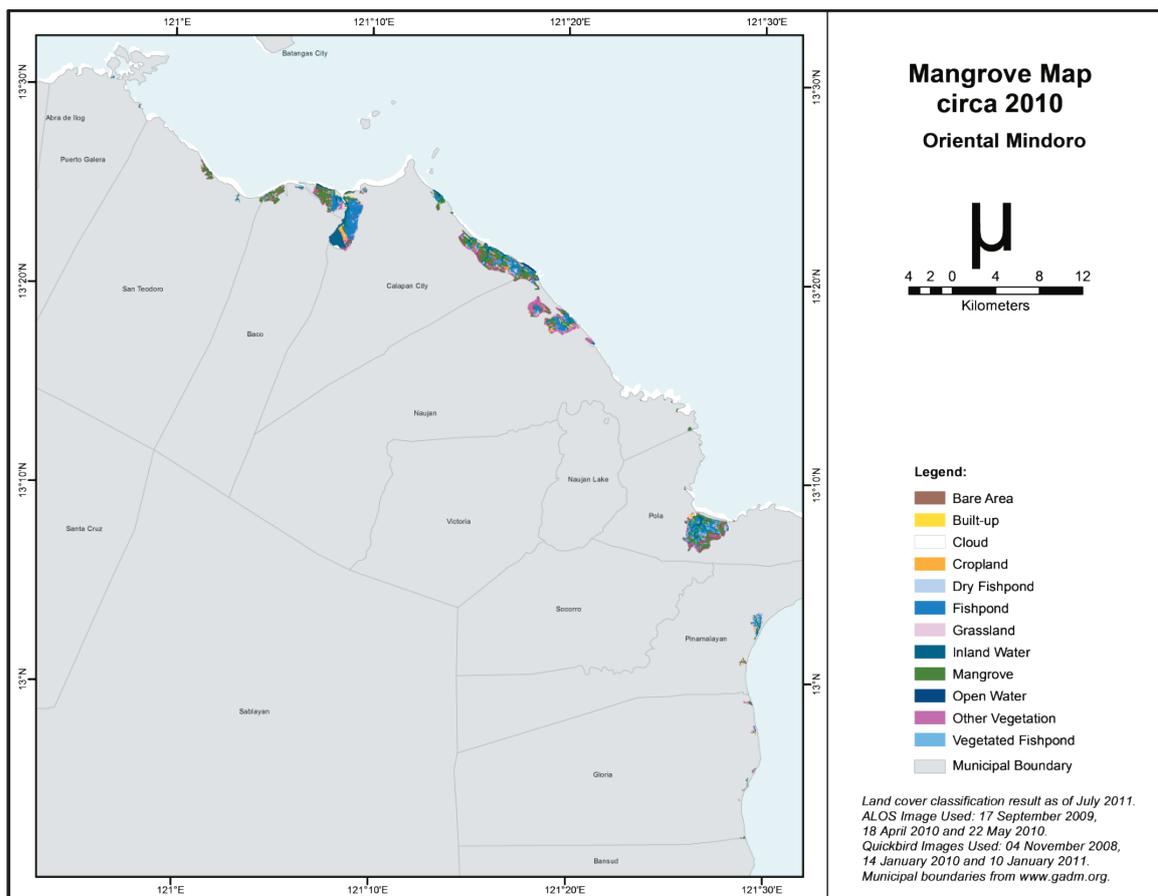


Figure 14. Circa 2010 map of the province of Oriental Mindoro.

Table 6. Per class areas for the Oriental Mindoro classification

| Class | 1990 Area (hectares) | 2010 Area (hectares) |
|---------------------|-----------------------------|-----------------------------|
| Built-up | 17.28 | 59.02 |
| Cloud | 80.55 | 1.09 |
| Shadow | 13.14 | 0.00 |
| Mangrove | 1,610.20 | 1,770.82 |
| Fishpond | 659.70 | 987.92 |
| Vegetated Fishpond | 73.80 | 170.06 |
| Dry Fishpond | 283.59 | 59.63 |
| Bare Area | 9.99 | 17.24 |
| Grassland | 532.88 | 488.64 |
| Other Vegetation | 1,110.82 | 641.31 |
| Cropland | 105.03 | 107.50 |
| Salt Bed | 0.00 | 0.00 |
| Open Water | 61.02 | 89.65 |
| Inland Water | 454.54 | 475.90 |
| Total Area = | 5,012.53 | 4,868.78 |

Accuracy Assessment

An overall accuracy of 83.12% and an overall kappa⁵ of 75.77% were obtained for the 1990 classification. Reasonably higher accuracies were obtained for the 2010 classification at 96.75% overall accuracy and 95.05% overall kappa. This was due to the fact that the validation data used in the accuracy assessment was acquired on dates closer to 2010 and so had greater agreement with the 2010 classification than the 1990 classification. It was highly likely that the actual land cover in 1990 already changed by the time the validation data were acquired, and that only a few of the original patches in 1990 were still there in 2010. Hence, the error matrix would exhibit more misclassification errors for ca. 1990.

The per class accuracy statistics for the two image dates are shown in Tables 7 and 8.

Table 7. Accuracy statistics for the circa 1990 classification

| Class⁶ | Ref.⁷ | Class.⁸ | # Correct⁹ | ProdAcc¹⁰ | UserAcc¹¹ | Kappa |
|--------------------------|-------------------------|---------------------------|------------------------------|-----------------------------|-----------------------------|--------------|
| built-up | 2 | 2 | 2 | 100.00% | 100.00% | 100.00% |
| mangrove | 58 | 55 | 47 | 81.03% | 85.45% | 70.50% |
| fishpond | 62 | 60 | 52 | 83.87% | 86.67% | 73.58% |
| veg. fp | 2 | 3 | 2 | 100.00% | 66.67% | 100.00% |
| dry fp | 12 | 12 | 11 | 91.67% | 91.67% | 90.96% |
| bare | 0 | 0 | 0 | - | - | - |
| grass | 8 | 8 | 6 | 75.00% | 75.00% | 73.63% |
| other veg. | 6 | 10 | 5 | 83.33% | 50.00% | 82.18% |
| crop | 1 | 1 | 1 | 100.00% | 100.00% | 100.00% |
| salt | 2 | 1 | 1 | 50.00% | 100.00% | 49.67% |
| veg. saltbed | 0 | 0 | 0 | - | - | - |
| bare saltbed | 0 | 0 | 0 | - | - | - |
| open water | 0 | 1 | 0 | - | 0.00% | - |
| inland water | 1 | 1 | 1 | 100.00% | 100.00% | 100.00% |

Table 8. Accuracy statistics for the circa 2010 classification

⁵ Overall accuracy only takes into account the percentage of correctly classified pixels with respect to the number of reference samples. Kappa, on the other hand, takes into account the effect of chance in the classification.

⁶ built-up (built-up areas), mangrove (mangrove areas), fishpond (fishpond areas), veg. fp (vegetated fishpond), dry fp (dry fishpond), bare (bare areas), grass (grassland), other veg. (other vegetation), crop (cropland), salt (salt bed), veg. saltbed (vegetated salt bed), bare saltbed (bare salt bed).

⁷ Ref. (reference) shows the number of validation points per class.

⁸ Class. (classified) shows the number of pixels classified into each class.

⁹ # Correct is the number of correctly classified pixels based on the validation data.

¹⁰ ProdAcc (producer's accuracy) is the probability that a pixel truly belonging to a class is classified into that class.

¹¹ UserAcc (user's accuracy) is the probability that a pixel classified into a class truly belongs to that class.

| Class | Ref. | Class. | # Correct | ProdAcc | UserAcc | Kappa |
|---------------------|-------------|---------------|------------------|----------------|----------------|--------------|
| built-up | 3 | 3 | 3 | 100.00% | 100.00% | 100.00% |
| mangrove | 54 | 54 | 53 | 98.15% | 98.15% | 97.15% |
| fishpond | 70 | 73 | 70 | 100.00% | 95.89% | 100.00% |
| veg. fp | 1 | 1 | 1 | 100.00% | 100.00% | 100.00% |
| dry fp | 5 | 3 | 3 | 60.00% | 100.00% | 59.21% |
| bare | 0 | 0 | 0 | - | - | - |
| grass | 8 | 8 | 7 | 87.50% | 87.50% | 86.82% |
| other veg. | 6 | 5 | 5 | 83.33% | 100.00% | 82.77% |
| crop | 3 | 3 | 3 | 100.00% | 100.00% | 100.00% |
| salt | 2 | 2 | 2 | 100.00% | 100.00% | 100.00% |
| veg saltbed | 0 | 0 | 0 | - | - | - |
| bare saltbed | 0 | 0 | 0 | - | - | - |
| open water | 0 | 0 | 0 | - | - | - |
| inland water | 2 | 2 | 2 | 100.00% | 100.00% | 100.00% |

Conclusions

The VIP mangrove and fishpond mapping showed an increase in the area of fishpond areas from 1990 to 2010 even after any mangrove rehabilitation efforts were undertaken. This implies that more protection and rehabilitation are needed to prevent decimation of mangrove areas.

If the areas classified as 'dry fishpond' and 'vegetated fishpond' were, indeed, "idle" or abandoned, these are, therefore, several potential areas for mangrove rehabilitation in the entire study area. These include the classified areas in the municipalities of Nasugbu, Calatagan, Lubang, and Looc.

Classification using the Landsat images was limited by the spatial resolution, especially, when compared with the ALOS and Quickbird classifications. This posed some difficulty in the interpretation of the images for image classification, especially, for fishponds and salt beds whose boundaries were not quite discernible on the Landsat images. On the other hand, the Landsat images made the discrimination of mangrove areas easier as compared to the ALOS and Quickbird images due to its near-infrared and infrared bands. These limitations, however, were successfully overcome and both classifications still yielded very good accuracies.



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